eRD107 (Forward HCal) R&D Project for Forward Hadron Calorimeter at the Hadron Endcap
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- We propose to build a full scale forward EMCal and HCal system. This R&D plan covers the Forward HCal component which consists of 36 longitudinally segmented towers. With the construction and beam testing of the calorimeter system, we expect to address all technical, performance and cost questions related to the final design of the Forward Hadron Endcap Calorimeter System (EMCal + HCal) for proposed EIC detectors and meet the requirements of forward calorimeter system specified in the EIC Yellow Report (YR).
- We expect that the R&D team will advanced the construction techniques based on STAR FCS that will be carried over to the EIC detector construction phase. Such development in both technological know-how and human resources will be valuable step towards the next phase of EIC detector development beyond FY2024.

We plan to address these technical questions with the proposed HCal prototype. A new efficient construction technology for HCal detectors was pioneered by the UCLA group and a large-scale detector, the STAR FCS HCal, was constructed in 2020 with this method. Following a recommendation from the advisory committee for EIC generic R&D program, the EIC IP design for an EIC reference detector was changed to accommodate additional space needed for ~7 interaction length hadron calorimeter in forward endcap region. Thus, this R&D aims at building a combined EMCal+HCal system, which will have ~7 interaction length depths and will meet performance requirements specified in the YR. Results from two independent MC simulations by the UCLA and the BNL group showed that the proposed HCal can meet the requirements from the YR, see Fig 1. This requires experimental validation with a full scale prototype that is sufficiently large to contain ~95% of hadronic showers energy as shown in Fig 1.

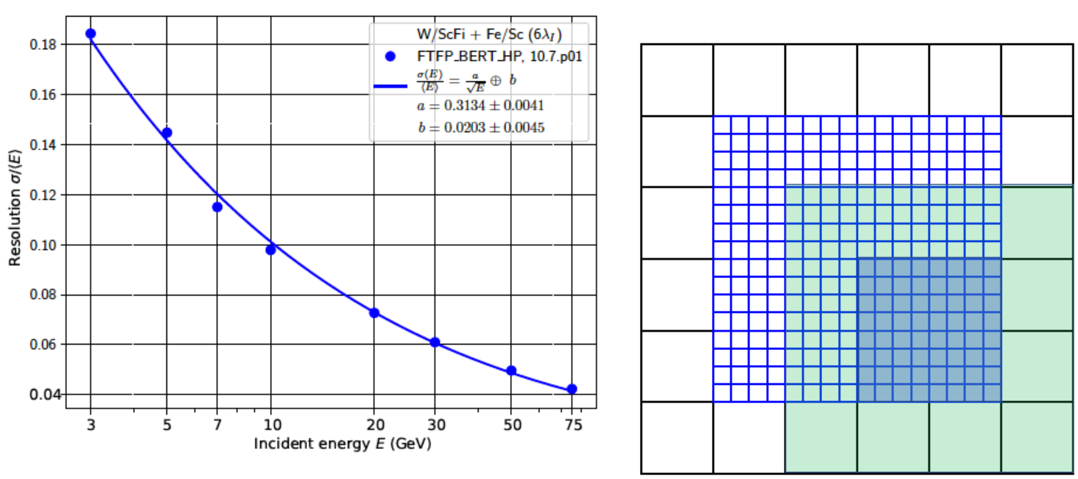

Figure 1. Energy resolution for hadrons in WScFi+ Fe/Sc calorimetry system. Front view of prototype. Instrumented 256 EMCal towers covering central region of HCal and 36 HCal towers. For comparison, shaded in green is a size of FCS HCal prototype and shaded in blue size of FCS EMCal prototype used in the FCS test run at FNAL in 2019.

ML/AI algorithms for jet energy reconstructions at EIC can enhance the performance with an optimal detector design. Application of ML/AI for calorimetry at EIC is a subject of general interest for all proto-collaborations. In particular, members of our R&D team from the UC EIC consortium supported by a UCOP MRPI grant for EIC (2021-2024) plan to develop ML/AI approach for EIC applications in next few years in collaboration with LBNL and LANL colleagues. In terms of detector configuration, we plan to optimize a transversely and longitudinally segmented calorimeter system. This is difficult to achieve in practice with 'standard techniques' used in the past due to space limitations and dead areas in the detector needed for highly segmented readout.

We propose to build a detector system fully compatible with very simple STAR FCS HCal system, which has a fine transverse segmentation (i.e. allowing re-using parts of STAR FCS for EIC detector). In addition, we propose to add longitudinal segmentations for the HCal section while still keeping the design of the system as compact and simple as the STAR FCS. Technically this can be achieved with a scheme similar to the one used in Caleido2 prototype for ILC. Each HCal tower will have four longitudinal segments which will be readout by two independent channels. These segments will use scintillation tiles with two different emission time constants, similar to the Caleido2 device. This is a cost-effective solution and is straightforward to adapt in our proposed detector configuration. The proposed segmented HCal allows for 3D imaging of hadronic showers at EIC.

An improvement in LY (compare to STAR FCS) is required for EIC HCal. This is driven by low energies of particles at EIC, requirements on lowest detectable energy and S/N considerations for jet reconstructions. A longitudinally segmented tower as described above allows to use SiPMs with larger pixel size. This improves PDE. A second important consideration is cooling of SiPMs for HCal. For STAR FCS decision was made not to cool SiPMs and the SiPMs were operated at very low bias voltages (this is driven by triggering requirements) at the expense of lower PDE. If desired LY for EIC can be achieved with sufficiently low bias voltages on SiPMs at EIC, then cooling of SiPMs for HCal may not be required. This will significantly simplify the integration of the readout system of the detector. We expect to reach a conclusion on this issue with the full scale prototype testing.

In FY22, we plan to start the construction of the proposed prototype. We plan to involve a large number of graduate and undergraduate students as much as possible similarly to what we had during the STAR FCS construction in 2020. This in particular requires that we must acquire all needed materials (scintillation tiles in particular) be ready for construction by the summer time of 2022. We will also perform optimization of light collection scheme. This will include measurements with cosmic muons using one test tower with different configurations of scintillating tiles (time constants), WLS plates and SiPMs. MC simulations will be performed to determine initial optimal configuration for longitudinal segmentations.

In FY23, we plan to finish the integration task (optical/mechanical/electronics) of readout. This includes optimization of FEEs (shaping for longitudinally segmented towers described above), production/testing/calibration of FEEs for the test Run. Development of software needed for the test run. Finally, we will perform a test run at FNAL with the combined full scale EMCal+HCal system with a streaming readout (TBD). The readout system for the test Run at FNAL will be an upgrade from the STAR FCS Detectors Electronics Platform (DEP) system.

Milestones for FY22:

- Production of majority of component needed for prototype.
- Optimization of light collection scheme for longitudinal segmentation.
- Measurements with longitudinally segmented tower with cosmic muons.

Preview for FY23.

- Optimization of readout scheme.
- Production of readout electronics.
- Production of SiPM boards.
- Test Run at FNAL

Institutions: ACU, BNL, IUCF, Rutgers, UCLA, UCR, Valpo
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Funding Profile:
FY22: ACU - $62.7k, Valpo– $59.7k, UCR- $47k, Rutgers $6.9k
FY23: UCLA - $101.5k, BNL -$20.4k, IUCF - $53.7
Can move Absorber Blocks into FY23

Material	Quantity	Price per Unit	Total Cost	+30% Contingency	Institution
Absorber Blocks	1836	$25	$45.9k	$59.7k	Valpo
Sc. Plates	459	$80	$36.7	$47.7k	ACU
WLS Plates	72	$350	$25k	$33k	UCR
Light Guides	72	$150	$10.8	$14k	UCR
Base Plates	1	$3000	$3000	$3.9k	Rutgers
Master Plates	24	$70	$1.6k	$3k	Rutgers
Dowel Pins/ Tyvek/Glues/Supplies	4k			$10k	UCLA
SiPMs	2304	$12	$28k	$36k	UCLA
SiPM Boards/Assemblies	72	$20	$2.5k	$4k	UCLA
FEE	72	$150	$11k	$14k	IUCF
Cables/Patch panels etc.	1	$40	$2.9k	$3.7k	IUCF
DEP Crate/boards	1/3		2k	$2.6k	BNL
LV Power supplies	3	contributed			UCLA

DAQ PC	1		6k	$7.8k	BNL
Trigger/Clock for Test Run			$10k	$10k	BNL
Shipping to FNAL	2	$6k	$12k	$12k	UCLA
Support Table/rotated	1	$5k	$5k	$6.5k	UCLA
Supplies/Tyvek/glue etc.		$5k	$5k	$5k	UCLA
Engineer Visser's Time	360 hours	$100/h	$36k	$36k	IUCF
Support Undergrads Labor (Sc tiles)			$15k	$15k	ACU
Travel (Oleg to diff. universities)			$10k	$10k	UCLA

Travel	Test Run FNAL		$15k	$15k	UCLA
Shipping to FNAL			$3k	$3k	UCLA

Total $351.9k